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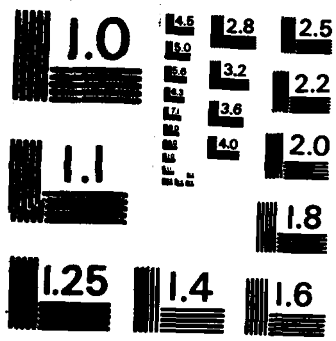

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VHF-AM Communications Equipment Selection and Installation Practices for Helicopters

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Final Report

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16. Abstract

This publication addresses the problems helicopter operators face when using VHF communications within typical operating environments where coverage by the network of ground stations may be deficient. This is of particular interest to IFR helicopter operators. The specific reasons why communications effectiveness can be limited in mountainous or remote regions, considering typical low helicopter operating altitudes, are reviewed. Recommendations to operators for improving the airborne VHF installation, and therefore improving its coverage capabilities, are presented.

Several installation-related factors are addressed. These include the characteristics of the hardware, i.e. the transceiver and the antenna, and the characteristics of the installation, including antenna installation and resulting coverage pattern, the cable run, the effects of signal availability and ways of maximizing the capture of the available signal. A set of procedures is presented which allows operators to evaluate numerically the benefit in terms of signal strength or sensitivity they may expect given that they make specific improvements to a given actual, or planned, installation.

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I. INTRODUCTION

This report addresses a long standing problem which affects a large segment of the helicopter operator community. Difficultly is experienced in using the existing network of VHF communications ground stations, since that network was not originally designed to service the unique requirements of many helicopter operators. VFR and IFR operations in mountainous areas and in remote and offshore regions are increasing substantially. Due to the line-of-sight nature of the VHF communications band, communications in critical phases of flight have been either problematic or impossible in many mountainous and remote areas. This is becoming even more serious due to the expansion in the numbers of IFR-capable helicopters whose operations are curtailed, or seriously inconvenienced, in such regions. Part of the solution to this problem is to find ways to maximize the performance of airborne VHF communications equipment installations in order to take best advantage of coverage that does exist. Often a station is available which covers a region of interest, but coverage dissipates at the lower altitudes at which helicopters operate. This is due to high intervening terrain, or to the effect of the radio horizon. If the performance of the airborne installation can be improved, then lower operating altitudes, or increased coverage ranges, may be realized.

Section 2 looks at the physical and economic reasons why constraints exist on the coverage of the VHF communications network. It reviews the limitations on locations available for VHF ground stations. It examines in detail the options available in the avionics market place, and the problems associated with comparing manufacturers' specifications. The antenna, its location and method of installation are reviewed in detail, along the problem of antenna interconnection with the transceiver.

Section 3 first presents a set of recommended practices for installing VHF communications avionics, antennas and interwiring. The second part of Section 3 presents computational techniques for evaluating the potential amount of improvement which may be realized by adopting some of the earlier recommendations. These techniques are also very useful for evaluating the relative benefits of competing system improvement alternatives to determine their worth to the operator. Finally, an example is presented of the potential benefit in enhanced range which could be obtained in a given set of circumstances.

Table 1.1 contains definitions for abbreviations and acronyms used in this publication. Appendix A is a table of selected specifications for an assortment of available VHF transceivers.

Table 1.1 Abbreviations and Acronyms

AGC	automatic gain control
Comm	communications
dB	decibels
dBm	decibels referenced to one milliwatt
dBw	decibels referenced to one watt
DC	direct current
DER	Designated Engineering Representative
D/U	desired to undesired signal ratio
ELT	Emergency Locator Transmitter
ERP	effective radiated power
g	force of gravity
Hz	Hertz (cycles per second)
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
KHz	Kilo-Hertz
MHz	Mega-Hertz
NAV	navigation receiver (VOR)
Pcr	received carrier power
RF	radio frequency
RTCA	Radio Technical Commission for Aeronautics
SNR	signal to noise ratio. Sometimes (S+N)/N
(S+N)/N	signal plus noise to noise ratio
TSO	Technical Standard Order
VFR	Visual Flight Rules
VHF	Very High frequency
VSWR	voltage standing wave ratio
W	Watts
μV	micro-Volts
Ω	Ohm

2. FACTORS LIMITING VHF COMMUNICATIONS EFFECTIVENESS

The following paragraphs address VHF communications system limitations present in both the ground station network and in the airborne installation. Emphasis is placed on understanding the physical and economic reasons for these limitations as well as their relative severity.

A. Ground Station Location, Siting and Terrain Factors

Several factors come into play regarding the choice of a location for VHF communications ground stations. Among these are:

- Operational Suitability -- proximity to the airspace and airports requiring coverage
- Ground-Link Availability -- availability of land lines (often leased) or microwave links to feed the ground station
- Operation and Maintenance Factors -- availability of power, environmental facilities, service roads, etc.
- Economics of Scale -- the economic motivation to physically group multiple radio facilities at one site.

In addition, site preparation requirements, surrounding terrain characteristics and frequency protection considerations impact the choice of a site, as well as its resulting performance.

Site Preparation -- This involves elimination or avoidance of nearby radio reflectors, such as metal buildings, antenna towers and utility towers, and elimination or avoidance of objects which would mask signals.

Terrain Characteristics -- Major terrain features (hills and mountains) may limit the desirability of a given site, or may limit the operational usefulness of a site where better alternatives do not exist. The high elevation of a mountainside installation may improve coverage on one side of the mountain while coverage on the other is nonexistent.

Frequency Protection -- The provision of adequate frequency protection (protection from interference from other VHF sites on the designated channel and on neighboring frequencies) must be demonstrated before an installation can be approved. The recent adoption of split channels (25 kHz spacing) has alleviated this problem to some degree. Unfortunately, most means available for improving the coverage of a given installation (power, sensitivity, antenna height, antenna directionality) also antagonize the frequency protection problem to the same extent that they improve coverage.

Often, the most desirable ground station sites (from the viewpoint of the IFR helicopter operator) fall short on one or more critical criteria. For example, a mountainside (or mountaintop) station site may be ideal for providing coverage over a wide area of hills and valleys,

but may suffer from lack of power, service roads or land lines, or may simply be an uneconomical installation from the standpoint of FAA facility establishment criteria.

The frequency protection issue is particularly problematic in the regions of current interest (remote areas and areas of high terrain). Signal availability for use in fringe coverage areas is defined in terms of signal-to-noise ratio (SNR, in dB), where the signal is attenuated due to remoteness and/or low operating altitude. The noise is the sum of ambient noise and receiver/antenna system noise. Frequency protection is described in terms of desired signal to undesired signal ratio (D/U, in dB). The dominant undesired signal may originate from a distant ground facility, or (with greater likelihood) from less-distant aircraft operating at normal altitudes at the fringe of coverage of that facility. Thus aircraft operating in remote areas may suffer a rapidly-diminishing desired signal, while the undesired signal changes negligibly due to the operating altitude of the interfering aircraft. Under such conditions, the D/U ratio degrades rapidly with decreasing altitude.

B. Airborne Equipment Factors

The specific characteristics of the airborne VHF transceiving equipment can substantially influence performance under fringe area conditions. The major performance factors are transmitter power, transmitter distortion, receiver sensitivity, receiver noise, receiver bandwidth and off-channel rejection characteristic.

RTCA has specified minimum performance standards for VHF airborne transmitting equipment in DO-186 (reference A). Minimum standards for these and other important parameters are listed in Table 2.B.1. Two classes of equipment of interest here are defined: Class 3 (200 mile maximum range, 25 kHz channel spacing) and Class 4 (100 mile maximum range, 25 kHz channel spacing).

Table 2.B.1 DO-186 Minimum Standards -- VHF Transmitter

Parameter	Class 3	Class 4
Output Power	16W	4W
Modulation	70%	
Distortion and Noise	25%	
Fidelity	350-2500 Hz, +0-6 dB	
Carrier Noise Level	35 dB down	
Frequency Tolerance	±.003% of Nominal	

These standards have been formalized and adopted by FAA in Order 6510.6, "U.S. National Aviation Standard for the VHF Air-Ground Communications Systems" (reference C). For the most part, the RTCA standards have been adopted. Transmitter output power is expressed in the National Standard in terms of the effective radiated power (ERP) required to produce an available received carrier power (Pcr) of at least -96 dBm at a given ground facility when at maximum desired coverage range. A plot is included in the VHF National Standard which presents theoretical coverage versus ERP, parameterized by altitude. This figure, reproduced here as Figure 2.B.1, shows that a 4 watt transmitter will achieve a 100 mile range at roughly 13,000 feet, and a 16 watt transmitter will achieve a 200 mile range at roughly 45,000 feet. This is equivalent to the RTCA Class 4 and 3 designation, respectively.

Appendix A presents the results of a survey of manufacturer's specifications for 49 different models of airborne VHF communicatons avionics. A review of that table shows that transmitter power levels vary from 5 to 25 watts. The panel mounted units span power levels from 5 to 16 watts. The remote units start at the 16 watt level. Thus the minimum power level for a Class 3 transmitter may be obtained in either the panel mount or remote mount configuration. Not all manufacturers listed transmitter distortion; of those who did, the typical maximum was 15%, which is better than the 25% minimum standard.

RTCA standards for VFR airborne receiving equipment are presented in DO-186 (reference A). That document categorizes receivers into four types, two of which are of interest: Class C (25 kHz channel spacing with off-set carrier operation) and Class D (25 kHz channel spacing with no off-set carrier operation). Off-set carrier operation is used for ARINC communications and other non-ATC applications, and so is not of direct interest here. These standards are summarized in Table 2.B.2. From a quick review of that table, it is obvious that the standards applying to receiving equipment are much more complex (and difficult to interpret from the layman's viewpoint) than those for transmitting equipment. A similar set of standards exists in the National Standard, including all of the above parameters. The standards are essentially equivalent, except that several parameters are expressed in terms of decibels (dB) rather than microvolts (μV). For example, minimum sensitivity to yield a 6 dB SNR is stated as -96 dBm, versus the Table 2.B.2 figure of 10 μV (under the same conditions). These two units of measure are, in fact, equivalent. This can be shown given that the characteristic impedance of free space is 377 Ω and

$$\text{Power Density} = \frac{(\text{Field Strength})^2}{\text{Impedance}} = \frac{(10\ \mu V)^2}{377\ \Omega} ;$$

$$= \frac{(10 \times 10^{-6})}{377\ \Omega} = 2.65 \times 10^{-13} w = -95.8\ \text{dBm}$$

Such major points of confusion leave a helicopter operator who is trying to compare different equipment specifications with little encouragement to do so. This is compounded by the tendency of most manufacturers to leave some parameters off of their published specifications, and to use

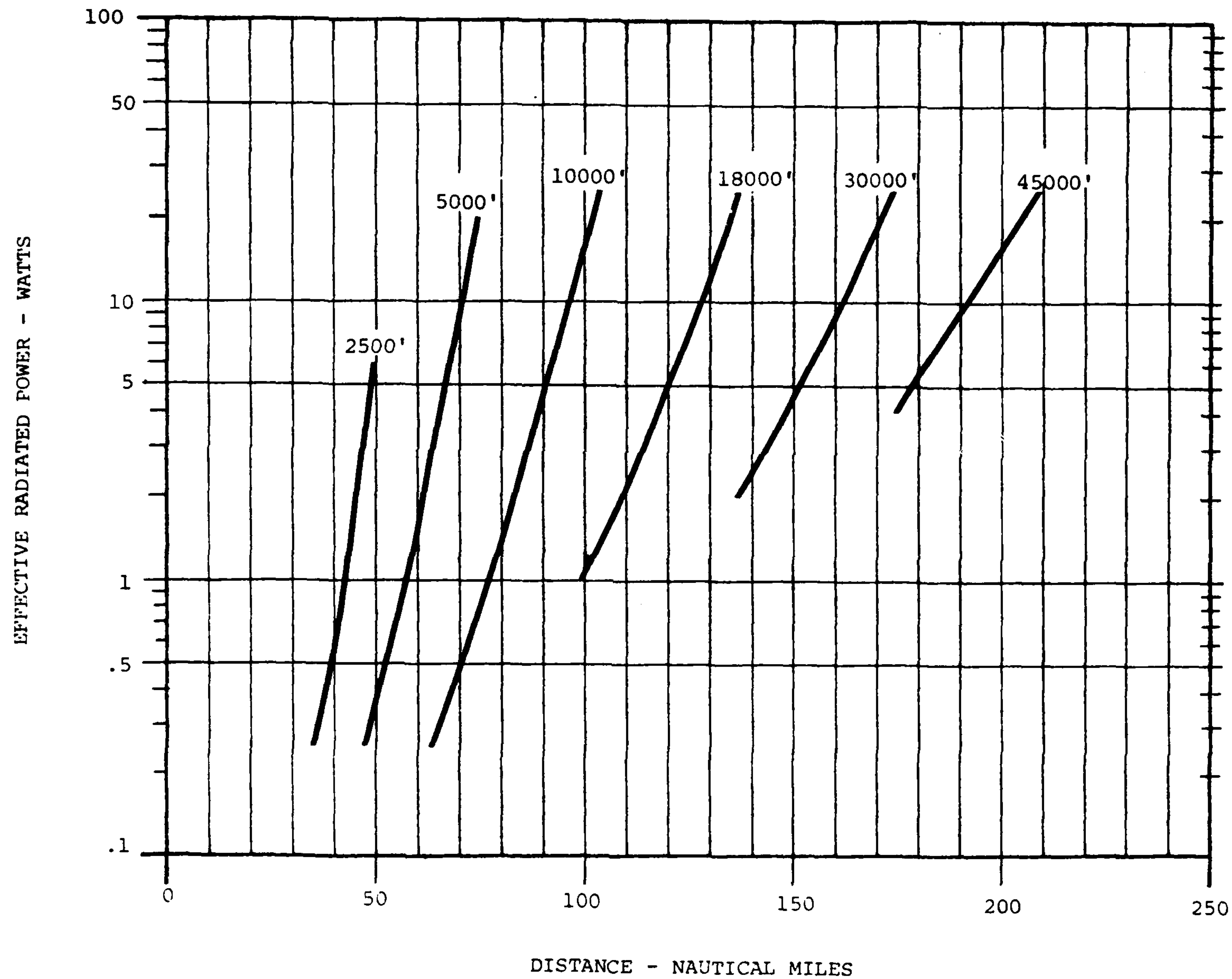


Figure 2.B.1 Effective Radiated Power Required Versus Distance for Selected Altitudes

Table 2.B.2 DO-186 Minimum Standards -- VHF Receivers

Parameter	Class C	Class D
Fidelity	350-2500 Hz, +0-6 dB	350-2500 Hz, +0-6 dB (>4000 Hz, >18 dB down relative to offset freq.)
AGC	Output constant within 6 dB, 10 μV to 100 mV	
Distortion	25% at 85% modulated at 10,000 μV	
Noise Level	25 dB down	
Sensitivity	10 μV at 30% modulated should give 6 dB SNR	
Selectivity		
Nose Bandwidth	±8 kHz, +0 dB-6 dB	±3 kHz, +0 dB-6 dB
Skirt Bandwidth	±17 kHz, 40 dB down ±25 kHz, 60 dB down	±22 kHz, 60 dB down
Spurious Responses	10,000 μV input required for 6 dB SNR (Interfering Signal)	
Cross Modulation	given 10,000 μV input, cross modulation should be >10 dB down from rated output	
Desensitization	given -82 dBm desired signal, SNR >6 dB required in presence of undesired signal at a level of -33 dBm	

varying methods for quoting the same parameter. This is illustrated in Table 2.B.3, which lists the sensitivity specification for a few selected VHF comm units (taken from Appendix A).

The most obvious discrepancy apparent on Table 2.B.3 results from the usage of the terms "hard" microvolts and "soft" microvolts. RTCA DO-186 recommends the usage of "hard" microvolts, which is defined to be the "open circuit" voltage from the signal source (i.e. the signal source is disconnected from the receiver input). "Soft" microvolts are measured when the source is connected and are, nominally, equal to one-half the "hard" microvolt level. This is true since the source impedance (nominally, at least) is equal to the load impedance of the receiver (and so one-half the power is dissipated by each). Due to the susceptibility of the "soft" measurement method to errors resulting from impedance imbalances, the "hard" method is preferred.

We can gain further insight into Table 2.B.3 by assuming two things:

1) "Soft" microvolts may be converted to "Hard" microvolts by multiplying by two;

2) Where not otherwise stated, values listed are "hard" microvolts.

Table 2.B.3 Selected Equipment Specifications

Manufact.	Model#	Sensitivity
EDO-AIRE	RT-551	3.0 μV open circuit (1.5 μV hard) for 6 dB (S+N)/N
KING	KX170B	1.5 μV soft provides a 6 dB minimum (S+N)/N
	KY196	2 μV (hard) or less for 6 dB (S+N)/N with 1 kHz tone modulated 30%
COLLINS	VHF-251	3 μV will provide 12 dB min (S+N)/N
CESSNA	RT-385A	3.0 μV Max for 6 dB (S+N)/N
	RT-1038A	1.5 μV for 6 dB (S+N)/N

Based on these assumptions, the RT-551 is seen to exceed the DO-186 requirement (10.0 μV open circuit for a minimum of 6 dB (S+N)/N). The RT-551 spec is self-contradictory for stating that 1.5 μV hard = 3.0 μV open circuit. For the KX170B, multiplying the "soft" spec by two yields a 3.0 μV/6 dB value. The KY196, however, appears to be better than that value in that only 2 μV are required to produce the desired SNR. The VHF-251 appears to be 6 dB better than the RT-551 performance. The RT-385A meets the RT-551 performance while the RT-1038A is better than that value, again by 6 dB just as the VHF-251 was, although it is not immediately obvious that

3 μV for 12 dB (VHF-251 Spec.)

is equivalent to

1.5 μV for 6 dB (RT-1038A Spec.)

even though they are mathematically the same.

In general, we may comparison-shop receiver sensitivities by applying two rules:

1) Convert stated "soft" microvolts to "hard" microvolts by multiplying by two.

2) Convert references to other than 6 dB (S+N)/N to that value by using the method in Section 3.B.2.

The results of a normalized comparison are listed in Table 2.B.4.

Table 2.B.4 Normalized Sensitivity Comparison

Model #	Sensitivity at 6 dB (S+N)/N
RT-551	3.0 µV
KX170B	3.0 µV
KY196	2.0 µV
VHF-251	1.5 µV
RT-385A	3.0 µV
RT-1038A	1.5 µV

A good final step in evaluating whether to purchase a given VHF comm set is to have the avionics shop doing your installation actually put the unit on the bench and measure important parameters, such as transmitter power, receiver sensitivity and nose bandwidth (or "acceptance" bandwidth). It is not uncommon for better-quality sets to exceed their specifications substantially. A 1.0 µV sensitivity is certainly not unobtainable.

Regarding the ability of a given VHF comm receiver to deliver intelligible voice communications in an operational environment, the raw receiver sensitivity value is only a starting point. Other important factors come into play. The 6 dB (S+N)/N figure is concerned only with noise generated internal to the receiver. There are four other important noise sources in an operational environment:

1) On-channel noise due to atmospherics and man-made ground-based noise sources.

2) On-channel noise from other co-channeled VHF stations (and their users) which may be inadequately frequency protected, or which may result from atmospheric "skip" conditions.

3) Off-channel noise from inadequately-rejected near-channel VHF stations (and their users).

4) Precipitation static noise (this becomes a factor on helicopters operating in IMC).

Noise received by the antenna may be far greater than quiescent atmospheric noise, let alone greater than internal receiver noise. The receiver has two means of combating noise:

1) limited bandwidth around the nominal channel frequency -- The amount of on-channel noise received by the set is directly proportional to the "nose" (or "acceptance") bandwidth.

2) sharp cutoff ("skirt" bandwidth, or "adjacent channel rejection") outside of the nominal channel bandwidth -- the degree to which off-channel noise can be rejected is controlled by the cutoff characteristic.

Figure 2.B.2 illustrates the bandwidth characteristic as specified in RTCA DO-186 for a Class D receiver, and shows one possible acceptable receiver response characteristic.

Many models of VHF communications equipment available today meet FAA Technical Standard Order (TSO) C37d (transmitter) and C38d (receiver) requirements, and state that fact in their literature. These TSOs directly reference RTCA DO-186. By meeting these standards the purchaser may assume that the minimum standards set by RTCA have been met. This is very important since any published manufacturer's specification is merely a claim, while to achieve TSO status the hardware must be subjected to a documented test procedure, the results of which are filed with the FAA. If one limits his shopping to TSO'ed hardware, the comparison becomes much easier, and performance factors compared may be limited to the following list:

Transmitter:
- Output Power
- Distortion and Noise

Receiver:
- Sensitivity
- Distortion
- Noise
- Selectivity
  - Nose Bandwidth
  - Skirt Bandwidth

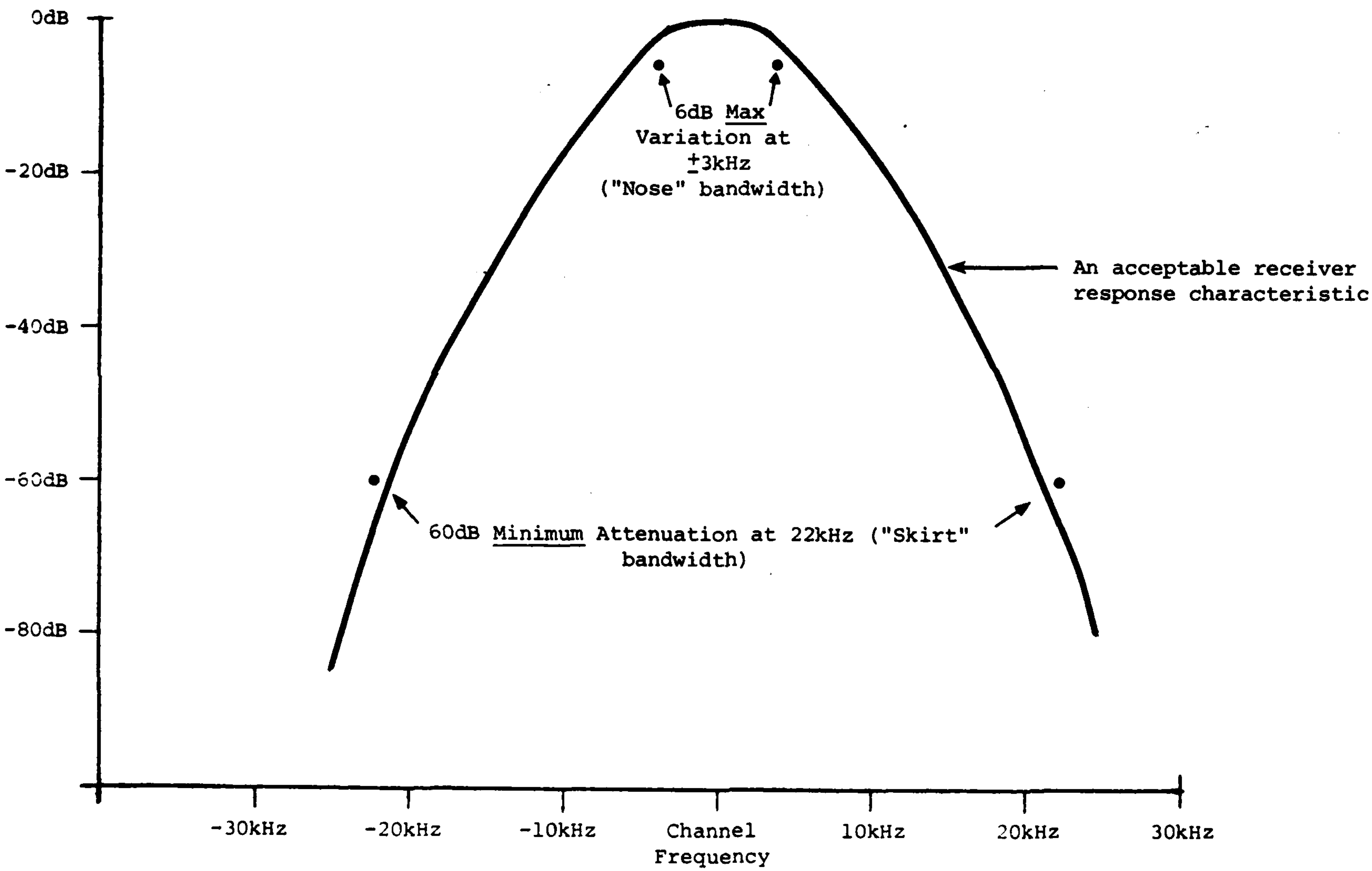


Figure 2.B.2 RTCA DO-186 Bandwidth Requirements (Class D Receiver)

Note in the above list the conspicuous absence of the parameter "Fidelity". This is intentional. The desired characteristic of a receiver is clarity, not fidelity. Clarity is a function of distortion and noise. "Higher" fidelity (wider "nose" bandwidth) only admits more noise, since the bandwidth of the transmitted signal is controlled. Therefore, one should shop for a set which provides minimum acceptable nose bandwidth and fidelity, and maximum "skirt" bandwidth attenuation (dB down at ±22 kHz).

There is one further paradox in the helicopter IFR VHF comm avionics equation, and that is the fact that sets with high powered transmitters are usually remotely mounted as opposed to panel mounted. This is a serious problem in most helicopters in that there is no radio rack, and little baggage or other available space to substitute. The weight-and-balance problem could also be aggrevated if a remote mounting were used. The survey in Appendix A shows that there is at least one panel-mounted 16-watt set now available. It is incumbent upon helicopter IFR operators to encourage avionics manufacturers to produce sets which meet their specific needs. The subject of remote mounted comm avionics will reappear elsewhere in this report. In general, remote mounting has several advantages if installation logistics can be overcome.

In summary, careful selection of VHF comm avionics can result in a considerable performance improvement over the equipment typically found in helicopters today. If a 16 watt transmitter is utilized, the advantage compared to a nominal 5 watt transmitter is 5.1 dB. This is enough to mean the difference between being "in" the noise or "well above" the noise at the receiving end. If a 1.0 μV sensitivity receiver can be obtained, that is equivalent to a 9.5 dB advantage over the commonly-available 3.0 μV receiver. While this cannot help where the desired signal is swamped by man-made noise or precipitation static, it is very advantageous in most fringe coverage area situations.

C. <u>Aircraft Antenna Design</u>

There are several critical antenna performance parameters of interest here:

- Physical Size
- Efficiency
- Directivity
- Noise Immunity
- Polarization

Before getting into the theory and problems of antenna design, it is necessary to appreciate the very significant constraints on antenna size which exist for small aircraft in general, and helicopters in particular. The wavelength at 125 MHz is 96 inches. Thus, even half-wavelength antennas are very large. Efforts to obtain some form of directionality (in azimuth) are doomed to failure since directional antennas invariably involve arrays of quarter-wavelength or half wavelength elements in some form or other.

The half-wavelength dipole, illustrated in Figure 2.C.1(a), is the most basic form of radio antenna. It is not suitable for aircraft use for VHF communications for the following reasons.

1) VHF comm signals are vertically polarized, which requires that the dipole be mounted vertically,

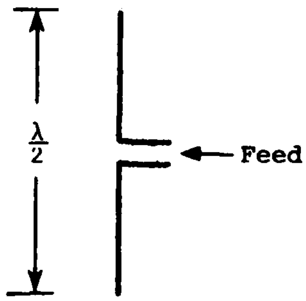
2) In order for a dipole to operate efficiently, it must be isolated from ground planes or other reflectors.

Thus the dipole would be suspended well above, or below, the helicopter, which is totally impractical.

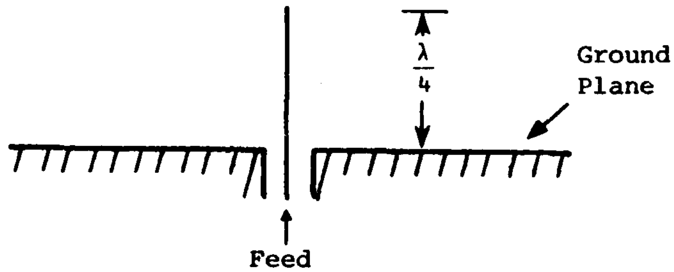
The quarter-wavelength monopole, illustrated in Figure 2.C.1(b), is embodied in one form or another in most VHF comm antennas sold today. The common, low-cost "cat's whisker" comm antenna is a form of monopole. Monopoles depend on the existence of a suitably large ground plane (aircraft skin) in order to operate efficiently. Often the antenna is physically shorter than its electrical length through use of a spiral conductor wound on a fiberglass base, or through other techniques. Some of these antennas are susceptible to lightning discharges and to precipitation static noise. Some are available with conductive coatings which minimize precipitation static noise. Until recently, precipitation static noise has not really been an issue in helicopter operations due to their VFR nature. However, the advent of IFR operations brings this subject new importance.

The monopole antenna is the simplest antenna practical for aircraft applications. Besides practicality, it enjoys an advantage of higher directivity (gain) compared to the dipole antenna. The dipole radiates both above and below the feed point. The far field of the monopole is indistinguishable from that of a dipole except that the field only exists above the ground plane. Thus all energy is radiated on one side (above the ground plane), giving a 3 dB directivity improvement to gain. Since the theoretical gain of a one-half wavelength dipole is 2.15 dB, the gain of the monopole is slightly in excess of 5 dB. Naturally, this is only beneficial if the ground plane (aircraft skin) is not shielding the antenna from the ground station. As a result, belly-mounted antennas are preferable at normal operating altitudes. Top mounted antennas are better during ground operations, and may well be better when operating at low altitudes in fringe coverage areas due to the characteristic role that the ionosphere plays in "bending" the radio waves over the optical horizon.

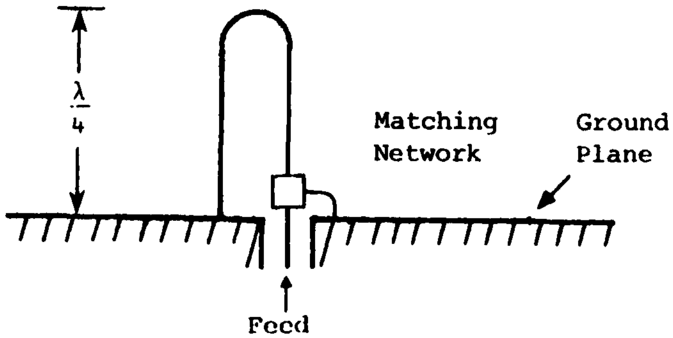
Another popular type of antenna used on aircraft is the folded monopole antenna, illustrated in Figure 2.C.1(c). The radiating element of this antenna is one-half wavelength long. However, it is folded in half with the far end connected to the ground plane. While at DC and low frequencies this represents a dead short to ground, at the design frequency it acts as an antenna with gains and radiating patterns similar to the monopole. The short-to-ground characteristic is very desirable,



2.C.1(a) Dipole



2.C.1(b) Monopole



2.C.1(c) Folded Monopole

Figure 2.C.1 Principal Antenna Types (Vertical Polarization)

since lightning discharges are shunted to ground, and particularly since precipitation static is almost non-existent.

The folded dipole is more expensive to manufacture than the monopole antenna, mainly due to the simplicity of feeding a monopole. The characteristic impedance of a monopole is 36 Ω, one-half that of a dipole antenna. This is not a bad match for the 50 Ω characteristic impedance of the coaxial cable and receiver/transmitter, and so efficiency is not badly compromised. (This is not to mention the considerable design effort expended by manufacturers in creating antennas which are smaller, have better bandwidth and more closely match the coaxial cable than does a simple, ideal one-quarter wavelength monopole.) The folded monopole, however, has a characteristic impedance of 144 Ω, one-half that of a folded dipole. This requires the use of more complex matching networks or transformers in order to produce an antenna with approximately 50 Ω input impedance.

The design of a practical folded monopole-type antenna may depart drastically from the ideal shown in figure 2.C.1(c), particularly in order to reduce the overall height of the antenna, and therefore its drag (these more expensive antennas are aimed primarily at the turbine aircraft market). They are much stronger than "cat's whisker" types and are capable of withstanding the drag and g-forces of high speed flight.

Regarding antennas for use on IFR helicopters, physical constraints of helicopter installation can compromise performance in terms of efficiency, noise immunity and polarization. Typically, an antenna designed for mounting on the bottom of the fuselage must have a low profile in order to avoid interfering with the ground. Commonly, monopole antennas with whip sections severely bent back are employed. Such designs compromise polarization since part of the antenna is horizontally polarized. This reduces the efficiency of the antenna regarding the desired signal, but not regarding noise (which is randomly polarized). Also, since these whip sections are typically metal and are isolated from airframe ground at radio frequencies, they are susceptible to precipitation static noise.

It is undoubtedly impossible to design a perfect VHF antenna for IFR helicopter applications, particularly given the constraints of a fuselage-bottom installation. It is hard to imagine an antenna of required electrical length which does not introduce some component of horizontal polarization sensitivity. However, an optimum design would probably consist of a folded monopole design, foreshortened or bent to reduce height, and less substantial in construction than available turbine aircraft antennas. Such a design probably does not currently exist. The best designs currently available are bent monopoles with metal whips which are DC-grounded, or of fiberglass construction with a factory-applied conductive coating to minimize precipitation static.

D. Antenna Location Factors

Regardless of the basic design of an aircraft VHF comm antenna, be it of the monopole or folded monopole class, two factors can seriously degrade its performance:

1) Lack of an adequate ground plane,

2) Nearby reradiating objects.

The fundamental principle of operation of a monopole antenna is based on the fact that it is located adjacent to a perfectly reflecting surface (electrically speaking). This is illustrated in Figure 2.D.1. The "image" of the monopole element is a complementary monopole which, when taken together with the original, appears identical to a dipole when viewed from the far field. If the ground plane is electrically large, then the image is perfect and the antenna is efficient and omnidirectional. If the size is severely restricted, or if the shape is highly irregular, efficiency will be compromised and/or directional lobing will occur.

Because of their very nature, helicopters present serious problems when siting antennas:

- Helicopters are typically relatively small
- As opposed to the "tubular" design of airplane fuselages, helicopters are irregular-shaped with very few clear expanses of sheet metal
- The fuselage bottom is interrupted by landing gear or skids (skids typically run the length of the bottom of the fuselage)
- The major portion of the frontal area is typically plexiglass
- The top of the fuselage also has an irregular shape, culminating in the rotor hub assembly
- The rear area transitions to the tail boom, which is often quite narrow.

Furthermore, even where a sufficient ground plane may be found, undesireable reradiators may be found in abundance. These include the skids (or landing gear), other antennas and the rotor blade assembly itself.

There are four primary locations commonly used for VHF antennas: 1) the fuselage underside, 2) the tail boom underside, 3) above the cabin (foreward of the rotor hub) and 4) topside aft of the rotor hub. The fuselage underside is usually the clearest ground plane area (it is the largest continuous surface and is typically made of sheet metal).

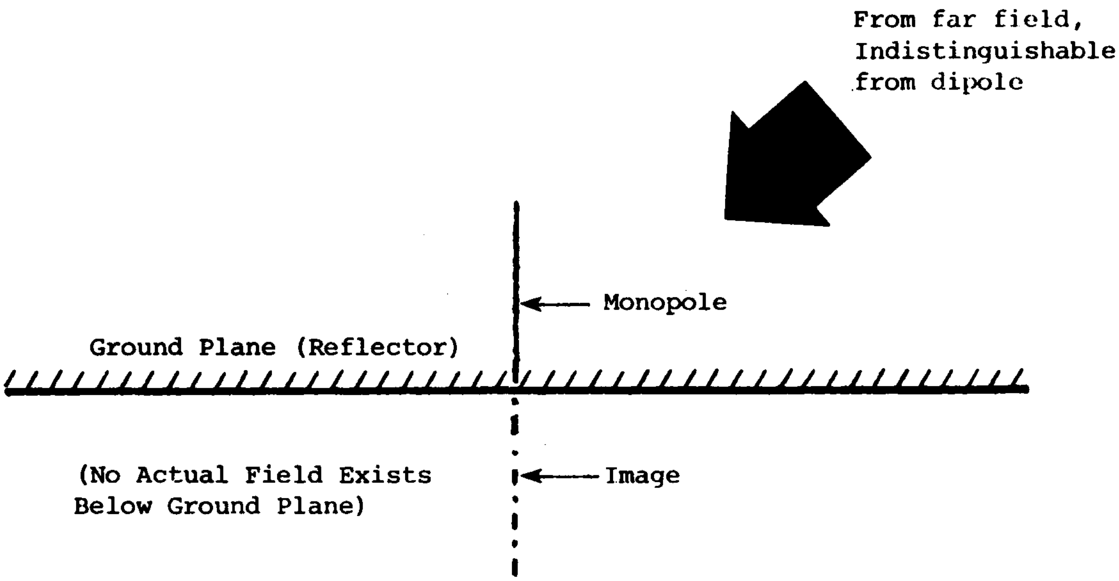


Figure 2.D.1 Dipole Equivalence of Monopole and its Image

However, it is usually cluttered with landing gear or skids, lights and other antennas. The tail boom underside can be a good site if the skin of the boom is sheet metal, and if the surface area (or boom cross section) is large in its forward section. Narrow diameter tail booms are much less adequate ground planes. Forward of the rotor hub topside is a good location if sufficient clear area exists. Often antennas are mounted immediately behind the windshield top edge, and so the ground plane is irregular and discontinuous. Antenna pattern lobing due to the presence of the rotor bub is unavoidable in any top mounting situation. Locating an antenna aft of the rotor hub, either on the engine cowling or aft of it, requires care. The cowling itself may not be metal. Even if it is, it has a highly irregular shape. Clearance from the rotor blade also limits the sites available.

It is readily apparent that most helicopters do not have a "good" VHF comm antenna site. The installation problem becomes one of determining the best choice of several possible compromises. The following guidelines can be used to aid this process:

1) While the fuselage underside is commonly preferable for the VHF comm antenna site in normal IFR operations, at least one of the VHF comm antennas should be sited topside if at all possible. This is preferable due to the typical low operating altitudes involved, and to the probability that a topside location will work better in an area remote from the VHF ground station.

2) The site chosen must be physically strong enough to support the antenna under the vibrational stress of a helicopter (often doubler plates or other physical modifications are used).

3) The site and adjacent ground plane areas must be metallic and well-connected to the aircraft structure. Fiberglass and composites may be metallized through the application of metal foil or copper mesh bonded to the surface, usually on the inside of the skin. Such metalization may be used to extend the area of ground plane if the metallized area is well connected to the adjacent metal skin to form a continuous electrical surface.

4) While it is preferable to avoid any nearby reradiating objects, this is not possible on a helicopter. However, location near antennas of similar wavelength <u>must</u> be avoided. These include other VHF comm antennas, ELT antennas and NAV antennas. Intra-antenna distances should be at least one-half wavelength (48") if possible in these cases.

5) Relocation of other existing or planned antennas should be considered in order to provide an advantageous site for at least one VHF comm antenna.

E. Antenna/Installation Longevity

Major antenna installation problems exist for helicopters which directly impact the ability to operate properly under remote/low altitude conditions. These problems have to do with deterioration of the installation with time and usage. Helicopters are particularly prone to loosening and cracking of antennas and corrosion for several reasons:

- In comparison to small fixed-wing aircraft, the helicopter environment is one of high vibrational stress and g-loadings (although aerodynamic loadings are normal)
- Leaks and normal corrosion are at least as prevalent as would be expected of fixed-wing aircraft
- Many of the helicopters of concern operate continuously in a salt-water environment.

The results of stress and corrosion are multi-faceted, although the symptoms are common: reduced sensitivity and/or high background noise and precipitation static. If the antenna structure itself becomes cracked or corroded, it becomes less efficient (lossy), and any previously-existing anti-precipitation-static treatments become ineffective. If the antenna mounting becomes loose, or water invades the metal-to-metal interface and corrosion results, the antenna is no longer well bonded to the airframe. Therefore, the effectiveness of the ground plane is reduced, and precipitation-static-resistance is reduced. Corrosion can even reduce the effectiveness of the electrical bond of one skin panel with adjacent

panels, causing the integrity of the ground plane to diminish and noise to increase.

Regarding cracked and corroded antennas, it is good practice to avoid antennas with exposed metallic parts, and to try to use antennas designed for a high-vibration environment. Surface preparation and mounting practices are covered in Section 3.

F. Antenna Cabling and System Installation Alternatives

The subjects of choice of locations for system components within an aircraft, and their interconnection, are often overlooked, even though they can affect overall performance. Several factors interrelate:

1) Installation costs (parts and labor)

2) Weight and balance effects

3) Performance and cabling losses.

A typical VHF comm installation may consist of two components: the panel-mounted, self-contained transceiver, and the antenna. Given the ins and outs of available cable routing paths, the actual length of coaxial cable between the two components may be far greater than expected. This is particularly true of topside and tail boom antenna sites. The most commonly used (and economical) coaxial cable is RG-58/U. Ignoring connector losses, bending and kinking, RG-58/U cable exhibits 5.7 dB loss per 100 feet at 136 MHz. If a cable run of 35 feet is involved, then 2 dB of transmitter power and receiver sensitivity are lost in the cable alone. Alternatives to RG-58/U exist and may be preferrable in many installations. However, penalties must be paid either in cable thickness and weight and/or cost.

3. OPERATOR ALTERNATIVES AND RECOMMENDED PROCEDURES

This section presents a set of recommended practices for optimizing a given VHF comm airborne installation. A set of techniques for estimating the benefits (in terms of received and transmitted power losses) or penalties of the various alternatives are presented. An interpretation of the potential benefit in terms of improved communications range of a given improvement (in dB) to the airborne installation is presented.

A. Recommended Equipment Installation Practices

A.1 VHF Transceiver Installation

(a) Panel Location: Panel-mount transceivers, or tuning heads for remote-mount transceivers, should be mounted in a location on the instrument panel where controls are readily accessed and displayed data are easily read. Manufacturer's mounting diagrams and recommendations should be adhered to for best system performance. Any special mounting brackets or shock mounts recommended by the manufacturer should be utilized. Proper attention to cooling requirements is necessary. If a unit requires forced air rather than convection cooling, proper air movement must be provided with a fan. If units are tightly packed together, consideration should be given to forced-air cooling regardless, since lower operating temperatures can significantly improve reliability. If a panel-mount unit with high transmitter power (16 W) is being used, special care should be exercised to ensure proper cooling of the transmitter output section. If ram air cooling is used, or if cabin air inlets exist near the panel, care must be exercised to ensure that rain water cannot be sprayed on the equipment.

(b) Remote Location: VHF transceivers employing a remote unit require mounting of that unit in the proper environment. Remote avionics units are normally mounted in the radio equipment rack. Most helicopters have no such provision, however. Candidate substitutes include baggage compartments or open dead space behind or below the cabin. To be suitable, such areas must

- be acceptable from a weight-and-balance standpoint
- be protected from weather intrusion
- be provided with an adequate flow of cooling air
- have power provided from an instrument panel circuit breaker
- be suitable from a mechanical standpoint (or be engineered by a DER) for mounting the equipment
- (if baggage compartment) provide protection from physical damage by baggage

The interconnection cable between the panel unit and the remote unit should be made in accordance with the manufacturer's recommended procedures.

All avionics installations (panel and remote) should follow the guidelines in Chapter 2 of reference B, "Acceptable Methods, Techniques and Practices -- Aircraft Alterations", AC 43.13-2A.

A.2 VHF Antenna Installation

(a) Choosing a Location: Very little suitable real estate exists on the skin of a helicopter for VHF antennas. Locations are usually a compromise between antenna performance, physical constraints and interference with other systems. Certain guidelines must be observed:

- A suitable ground plane must be provided
- Minimum spacings (at least four feet) from other similar antennas (VOR, VHF Comm, ELT) must be provided.
- Clearance from the ground under hard landing conditions must be provided (bottom installations)
- Clearance from the rotor blades during the flexure experienced during hard landings (topside installations)

Without a suitable ground plane, the antenna will be quite inefficient and may exhibit undesirable directional nulls. Closely-spaced VOR and Comm antennas result in comm-to-nav or comm-to-comm interference. Also, both antennas involved will exhibit undesirable directional characteristics. Close proximity to the ELT antenna also produces directional nulls. Furthermore, some ELTs radiate broadband noise when excited by a comm transmission. The ground and rotor clearance requirements are necessary to maintain structural and rotor blade integrity.

On dual-comm installations, the antennas should be separated by at least four feet. If possible, one should be mounted topside, while the other is on the bottom. Usual practice on fixed-wing aircraft is to connect the bottom antenna to Comm 1 and the top antenna to Comm 2. However, for IFR helicopters that customarily operate in fringe VHF coverage areas, it may be advantageous to connect the more powerful and/or sensitive transceiver (where two different units are employed) to the top antenna due to better coverage at low altitudes and in fringe areas.

Where the desired mounting location is on a nonmetallic surface, such as a composite structure, two factors must be addressed: mechanical integrity, and adequate ground plane. The ground plane issue may be resolved by installing metal foil or copper mesh on the inside of the skin, electrically bonded to the antenna ground and to any adjacent metal structures. If a metal doubler plate is called for to enhance mechanical strength, it may substitute for all or part of the foil ground plane. Alternatively, the foil may be applied to the exterior and covered with resin, or painted over. If there is any question concerning the mechanical aspects of the mounting a DER should be consulted.

(b) Installation Guidelines: Antenna installations should be made in accordance with the guidelines in Advisory Circular AC 43.13-2A (reference B). Several aspects of antenna installation technique should be stressed:

- electrical bonding to the ground plane
- corrosion and sealants
- connector corrosion
- painting
- precipitation static prevention
- VSWR check

A good electrical bond between the coaxial cable braid, the antenna ground connection and the ground plane is essential for proper operation of the ground plane. The fact that the sheet metal and the transceiver ground are all connected to frame ground somewhere other than at the antenna mounting point is not sufficient. The components may all be at common DC ground potential, but may be several wavelengths away from being at common RF ground potential unless the bond is made at the mounting point. Remove paint around mounting holes and use external-tooth lockwashers. Use an electrically-conductive primer if necessary to secure a good connection.

Mounting holes and metal-to-metal joints should be sealed in accordance with the antenna manufacturer's instructions or AC 43.13-2A (reference B). The object is to prevent corrosion from deteriorating the electrical ground bond, or from damaging the antenna. Examine the hull for evidence of water leaks which could advance corrosion at or near the antenna position. Corrosion between adjacent aluminum skin sections, or the skin and the frame stringers, can result in poor performance and noisy reception. Where such a situation exists, the skin must be stripped and the corrosion removed. Antenna connector corrosion is easily prevented through application of silicon grease to both mating halves. This prevents the intrusion of moisture.

Most antennas will not perform properly if covered with paint. If paint must be used, the antenna manufacturer should be consulted. The best general rule is to never apply any paint over any antenna.

Antennas should be chosen with precipitation static considerations in mind. If the manufacturer has anti-static coatings available for their antennas, make sure that the coating is obtained, properly applied and maintained.

A good method for checking antenna installation and identifying installation problems is a VSWR (standing wave) test. This may be done by inserting an in-line type wattmeter between the transmitter and the coaxial cable. The measured VSWR should approximate the manufacturer's specification. If significantly higher VSWRs are measured, the coaxial cable, antenna and ground plane should be investigated.

A.3 Coaxial Cable Installation

The coaxial cable run should be as short as possible, while avoiding sharp bends or kinks. Bends and kinks in coaxial cable seriously degrade performance, since a sharp bend deforms the cable from its nominal circular form, therefore abruptly changing its impedance. Part of the transmitted signal will reflect at that point, causing a standing wave in the line. Therefore, part of the signal never gets to the antenna. (Conversely, part of the received signal never gets to the transceiver).

The length of the cable should be minimized to reduce signal losses in the cable. If a run longer than 15 feet is involved, consideration should be given to using RG-8/U cable if its added weight and bulk can be accommodated. If the size of the cable is a problem, more expensive low-loss cables with silver-plated conductors should be considered.

Cable termination practices are as important as antenna mounting practices. One continuous length of cable should be used; splices and in-line connectors should be avoided due to added losses and potential for corrosion. Care should be exercised when terminating cables to ensure that moisture will not penetrate to corrode the connections internal to the connector body. Connector termination practices are covered in AC 43.13-2A (reference B).

B. Methods for Evaluating Hardware and Installation Alternatives

B.1 Transmitter Power Comparison Method

Transmitter output power is normally quoted in watts at 85% modulation, with the associated distortion level stated (which should be 25% or less). Watts may be converted to decibels (dB) as follows

$$dB = 10 \cdot \log(\text{watts}) \tag{1}$$

Thus, a 5 watt transmitter has an output power of 7.0 dB. In radio communications analysis power levels are often expressed in dBm, which are decibels relative to one milliwatt:

$$\begin{aligned} dBm &= 10 \cdot \log(\text{milliwatts}) = 10 \cdot \log(1000 \cdot \text{watts}) \\ &= 10 \cdot \log(\text{watts}) + 10 \cdot \log(1000) \\ &= dB + 30 \end{aligned} \tag{2}$$

Expressing power relative to one milliwatt merely changes the reference datum; one may always go back and forth between dB and dBm by adding or subtracting 30. The 5 watt transmitter of the above example can be expressed as 37.0 dBm.

The advantage of a more powerful transmitter may be expressed either by calculating the absolute power in dBm

$$16 \text{ Watt transmitter} = 10 \cdot \log(16000) = 42.0 \text{ dBm} \tag{3a}$$

and subtracting the 5 watt transmitter power of 37.0 dBm to yield a gain of 5 dB, or by taking the ratio of the power levels and converting that the dB:

$$10 \cdot \log (16 \div 5) = 5.0 \text{ dB} \qquad (3b)$$

Gain values for several common power levels are listed below.

Power	Gain/relative to 5 watts	
5W	0.0 dB	
10W	3.0 dB	(4)
16W	5.0 dB	
25W	7.0 dB	

B.2 Receiver Sensitivity Comparison Method

Receiver sensitivity is expressed in terms of receiver input level in microvolts (μV) required to produce a stated signal + noise to noise ratio (S+N)/N. The standard minimum requirement of reference B is

10.0 μV (hard) for (S+N)/N = 6.0 dB (5)

To determine the relative sensitivity (in dB) of a given receiver relative to a nominal receiver with a 3.0 μV/6.0 dB specification, it is necessary to perform three steps:

I. Convert "soft" μV to "hard" μV:
"Hard" μV = 2 • "soft" μV (6)

II. Adjust μV for (S+N)/N other than 6.0 dB:
Given a specification stating an (S+N)/N value of y dB,

$$\mu V \text{ (referenced to 6 dB)} = \mu V \text{ (referenced to y dB)} \cdot 10^{\frac{(6-y)}{20}} \qquad (7)$$

Example: Given 3.0 μV at (S+N)/N = 12 dB

$$3.0 \cdot 10^{\frac{(6-12)}{20}} = 3.0 \cdot 0.5 = 1.5 \ \mu V \text{ at (S+N)/N} = 6 \text{ dB}$$

III. Convert resultant μV level to dB gain over the nominal:

$$\text{Gain (relative to 3 } \mu V) = 20 \cdot \log \left(\frac{3.0}{\mu V \text{ referenced to 6 dB}} \right) \qquad (8)$$

Continuing the above example:

$$20 \cdot \log \left(\frac{3.0}{1.5} \right) = 6.0 \text{ dB}$$

Note that even the nominal 3 μV receiver enjoys an advantage of 10.5 dB over the minimum requirement (calculated by the same method).

B.3 Coaxial Cable Loss Calculation

Coaxial cables exhibit very predictable ohmic loss characteristics which are functions of frequency and cable length, and which vary by type

of cable. In general, large diameter cable types, such as RG-8/U, are less lossy than common small diameter types, such as RG-58/U. RG-8/U, which is 0.405" large (outside diameter) shows a characteristic loss of 2.6 dB per 100 ft at 136 MHz. RG-58/U, which is 0.193" large (outside diameter) has a characteristic loss of 5.7 dB per 100 ft at 136 MHz. Besides being much less flexible and harder to install, RG-8/U weighs 11 pounds per 100 ft compared to 2.6 pounds for RG-58/U, and costs about three times as much. The table below list pertinent characteristics for several types of 50 Ω coaxial cable.

Type	Diameter	Loss*	Weight*	Relative Cost**	Material	
RG-8/U	.405	2.6 dB	11.1 lb	3.2	Bare Copper	
RG-58/U	.193	5.7 dB	2.6 lb	1	Tinned Copper	
RG-141/U	.190	3.7 dB	3.8 lb	6.7	Silver Coated	(9)
RG-142/U	.195	4.5 dB	4.5 lb	8.8	Silver/Double Shield	
RG-179/U	.100	11.7 dB	1.9 lb	2.7	Silver Coated	
RG-214/U	.425	2.6 dB	13.3 lb	16.1	Silver/Double Shield	

*per 100 feet
**relative to RG-58/U

Types RG-142/U and RG-214/U are representative of low-loss, double shielded types which can be used where cable emissions are a problem. Type RG-141/U is representative of a low-loss, small diameter cable (equivalent to RG-58/U). It is quite expensive due to the use of silver plated conductors. Even at that, losses are higher than RG-8/U. Reduction in losses to be expected in a given installation due to the use of some cable other than RG-58/U may be calculated as follows:

$$\text{Loss Reduction (dB)} = \text{Cable Length} \cdot (5.7 - \text{Cable Loss}) \div 100 \qquad (10)$$

For example, in a 35-foot installation with a cable loss of 2 dB (RG-58/U), usage of RG-8/U would provide a loss reduction of 1.1 dB.

B.4 Antenna Gain and Efficiency Comparison

Monopole and folded monopole antennas exhibit approximately the same gain characteristics due to directivity. The gain is equal to that of a half-wave dipole (2.15 dB), plus a 3 dB advantage due to the fact that in the monopole case, the field only exists in half of space (thus the power in that space is doubled). Therefore, a monopole has a gain of roughly 5 dB. There are several factors which reduce the effective gain of an installed antenna. The impact in dB of each factor may be calculated or estimated.

- Antenna ohmic loss inefficiency
- Cable/antenna impedance mismatch (VSWR)
- Polarization mismatch to the ground transmitter
- Ground Plane inefficiency
- Radiation pattern variations

The ohmic loss inefficiency value is usually found in the manufacturer's specifications expressed as a fraction (e.g. 85% efficient). In dB it may be expressed as follows:

$$\text{Ohmic Loss} = 10 \log (\text{efficiency}) \tag{11}$$

Example

$$10 \log (0.85) = -0.7 \text{ dB}$$

The cable/antenna mismatch results in a voltage standing wave ratio (VSWR) greater than unity, indicating that some power is being reflected and lost. The impedance mismatch factor, q, is defined as follows:

$$q = 1 - \left| \frac{\text{VSWR}-1}{\text{VSWR}+1} \right|^2 \tag{12a}$$

or in dB:

$$10 \cdot \log(q) = 6.0 + 10 \cdot \log(\text{VSWR}) - 20 \cdot \log(\text{VSWR} + 1) \tag{12b}$$

Losses for typical VSWR values are listed below. For a given installation, the actual VSWR at the transmitter terminals may be measured to get the overall installation loss due to impedance mismatches.

VSWR	Impedance Mismatch Loss
1.0	0 dB
1.5	-0.2 dB
2.0	-0.5 dB
3.0	-1.3 dB

(13)

The polarization mismatch is difficult to quantify exactly since it is difficult to determine an antenna's exact polarization angle just by examining it. For vertical whips and blade antennas it may be assumed to equal one (zero dB loss). For angled and bent whips, estimate an overall effective angle from vertical. The polarization mismatch factor, p, is defined as follows:

$$p = \text{Cos}^2 (\Upsilon), \ \Upsilon = \text{Polarization Angle} \tag{14a}$$

or in dB

$$10 \cdot \log (p) = 20 \cdot \log \text{Cos} (\Upsilon) \tag{14b}$$

Losses for typical polarization angles are listed below.

Polarization Angle	Polarization Mismatch Loss
0°	0 dB
20°	-0.5 dB
45°	-3.0 dB
60°	6.0 dB

(15)

Ground plane inefficiency, unfortunately, is difficult to estimate. If overall ground plane size is sufficient (minimum 24 inches radius), then proceed to the next topic, radiation pattern variations, since most ground plane imperfections result in pattern lobes and nulls. If a small ground plane is in use, the only recourse may be to make a relative field strength measurement (see next topic) between the antenna as installed, and the same antenna temporarily attached to a large sheet of aluminum suspended from the helicopter in a horizontal configuration. Calculate dB loss as in equation (16).

Radiation pattern variations may be estimated using a ramp signal generator and a short stub antenna on a stand designed to raise the stub antenna to the height of the antenna under test. Instrument the receiver to be able to measure some specified value of radio frequency amplitude at the receiver antenna terminals which is well above ambient noise (e.g. 20 μV). Locate the helicopter under test in a field away from hangar buildings, etc. With the ramp generator stub antenna a sufficient distance from the aircraft (e.g. 50 feet), measure the transmitter signal amplitude required to induce the desired received signal amplitude at multiple locations in azimuth around the aircraft (30^{o} increments are suitable). Calculate pattern variation inefficiency as follows

$$\text{Pattern loss} = 20 \cdot \log \left(\frac{\text{Lowest Transmitter Amplitude}}{\text{Highest Transmitter Amplitude}}\right) \qquad (16)$$

For example, if the lowest transmitter signal value were 1200 μV (most sensitive point), and the highest value were 2200 μV (least sensitive point), then the loss due to pattern inefficiency would be:

$$\text{Pattern loss} = 20 \cdot \log \frac{(1200)}{(2200)} = -5.3 \text{ dB}$$

B.5 Overall Installation Evaluation

Based upon the previous sections, the attributes of a given comm installation may be organized into two groups:

<u>Avionics Attributes</u>: Consider either transmitter power in dB relative to a nominal 5-watt transmitter, or receiver sensitivity in dB relative to the RTCA minimum standard of 10.0 μV at $(S+N)/N = 6$ dB. These attributes would not be summed together. Relative receiver sensitivity in dB may be calculated using equation (8). These attributes may be used to compare competing avionics equipment, or to assess the relative performance of a planned installation relative to an existing installation.

<u>Installation Attributes</u>: The sum of cable loss + antenna gain + impedance mismatch loss + polarization mismatch loss + ground plane loss + antenna pattern loss, which could be called aggregate installation loss, is in effect during both transmit and receive operations. Therefore, it may be added to either the transmitter power or receiver sensitivity attributes listed above in order to arrive at the overall installation performance.

Note that the installation attributes above result typically in a net loss value; i.e. the cable loss, impedance mismatch loss, polarization loss, ground plane loss and antenna pattern loss are all negative (or zero) values, while the antenna gain is positive.

In order to relate the expected performance of a given installation to real-world conditions, it is first necessary to examine the available power budget under ordinary circumstances. From DO-186 (reference A) we see that a 4-watt transmitter is expected to reach a line-of-sight range of 100 nmi. The line-of-sight range equation for free space loss is

$$L = 20 \cdot \log (4 \pi d/\lambda) \text{ in dB} \tag{17a}$$

at 120 MHz and with d expressed in nmi,

$$L = 79 + 20 \log D_{nmi} \text{ in dB} \tag{17b}$$

Therefore, at 100 nmi, L = 119 dB.

The 4 watt transmitter output power corresponds to a level of 36 dBm:

$10 \cdot \log (4) + 30 = 36$ dBm (from equation 2)

From Section 2.B the receiver minimum sensitivity is -96 dBm. Therefore the power budget is

Power Budget = Transmitter Power less Receiver Sensitivity
= 36 dBm - (-96 dBm) = 132 dB

Of that power budget, 119 dB are accounted for by path loss alone (equation 17b). Therefore, the airborne installation must be assumed to account for 13 dB in losses. If a given installation can be shown to have a lower loss figure than 13 dB, better performance than nominal could be expected. This will result in increased range and/or better coverage at low altitudes.

Since the 13 dB installation loss value can be assumed to contain a 5 dB nominal antenna gain, the losses due to cabling, antenna efficiency, impedance mismatch, polarization mismatch, ground plane and antenna pattern losses must be assumed to equal 18 dB (13 + 5). It should not be difficult to achieve much better performance than this. Consider the following conservative example:

Example Installation Loss Budget

Item	Value	Relative to
Transmitter Power 16 Watts	6.0 dB	4W Transmitter
Coaxial Cable (18 ft RG-58/U)	-1.0 dB	
Antenna Efficiency	-1.0 dB	80% Efficient
VSWR = 2.0	-0.5 dB	
Polarization Angle = 20°	-0.5 dB	
Ground Plane	0 dB	Assumed Perfect
Pattern Loss	-5.3 dB	from example Section 3.B.4
Net	-2.3 dB	

Therefore, in this example a net improvement of 15.7 dB over the nominal 18 dB loss would exist. Therefore, an increased path loss of 134.7 dB, rather than the nominal 119 dB, could be covered.

Since the circumstances we are concerned with are beyond line of sight limitations due to low operating altitudes or intervening terrain, the increase in line-of-sight coverage which this could provide is not of direct interest. In reference D, VFH path losses due to low altitudes and surface roughness (but not mountainous terrain) are modeled in detail. While the models which result do not necessarily replicate any specific physical location, they are representative of remote area operations in general. The example plot in Figure 3.B.1 is representative of an aircraft flying at 1000 feet, communicating at 120 MHz with a ground station whose antenna is on a 50 foot tower. There is intervening hilly terrain characterized by a terrain parameter (as defined in reference D) of 250 feet. Three curves are shown, the lowest of which is of interest here since it represents a 95% probability over the long term that the transmission loss is at least the value indicated. Three points on this graph are of interest. Point 'A' represents the free-space line-of-sight case, giving 100 miles of coverage for 119 dB of path loss. Point 'B' shows the over-the-horizon restriction to range, resulting in only 25 miles of coverage for 119 dB of path loss. If allowable path loss were increased by 15.7 dB through improvements in the airborne installation over the nominal case, we arrive at point 'C', which shows a coverage of 43 miles for 134.7 dB of path loss. The additional 18 miles (72% increase) represents an increase in station coverage <u>area</u> of 195% (nearly 3 times the coverage) under these specific circumstances.

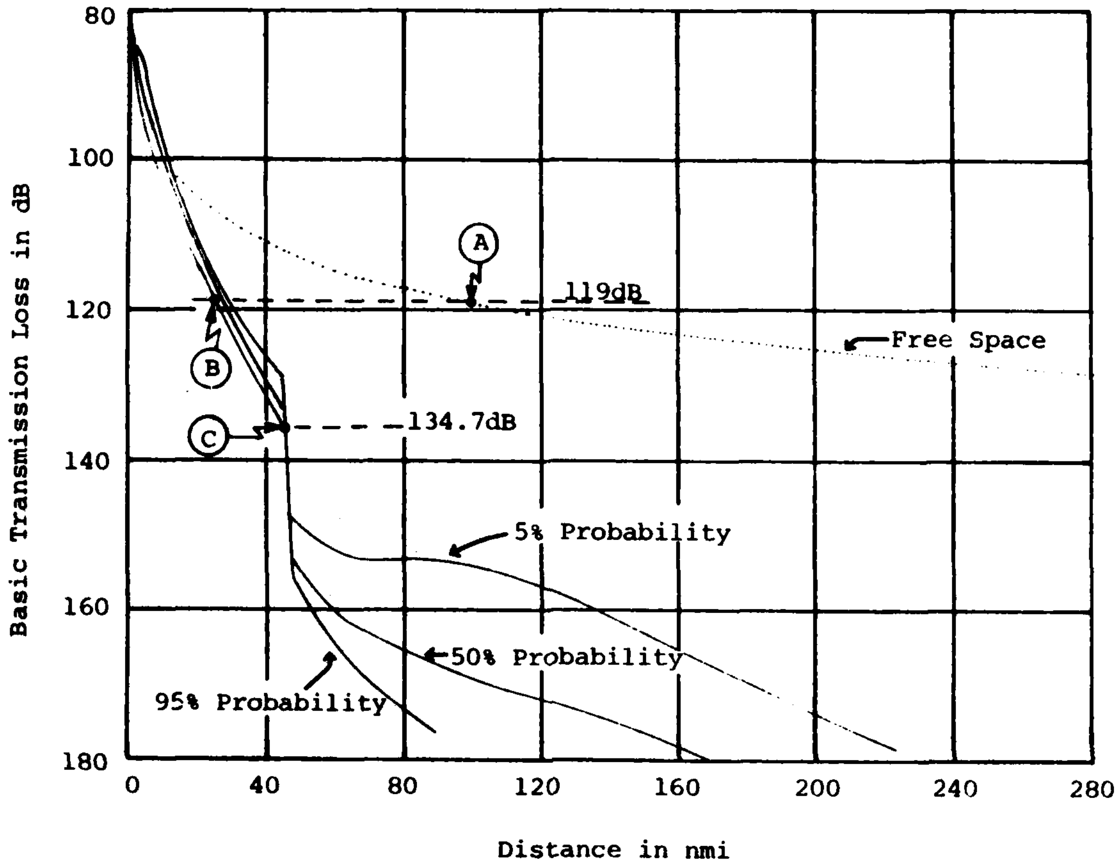


Figure 3.B.1 Predicted Values of Basic Transmission Loss (Hilly Terrain)

References

A. "Minimum Operational Performance Standards for Airborne Radio Communications Equipment Operating within the Radio-Frequency Range 117.975-137.000 Megahertz", Document No. DO-186, January 1984, RTCA.

B. "Acceptable Methods, Techniques and Practices -- Aircraft Alterations", AC 43.13-2A, 1977, FAA, DOT.

C. "U.S. National Aviation Standard for the VHF Air-Ground Communications System", Order 6510.6, 11/11/77, FAA, DOT.

D. "Characterization of a VHF Air-Ground Channel", G.A. Hufford, A.G. Longley, OTR Report 74-47, Office of Telecommunications, Department of Commerce, October 1974.

APPENDIX A

VHF COMMUNICATION SYSTEM SPECIFICATIONS SUMMARY

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
EDO-AIRE	RT-563		360	3.0 μV hard (1.5 μV) open circuit for 6 dB (S+N)/N	See RT-551	5 Watts			Panel Mounted Nav/Com
EDO-AIRE	RT-563A		720	See RT-563	See RT-551	See RT-563			Panel Mounted Nav/Com
KING	KU191	N/A	1	1.5 μV soft will provide a 6 dB minimum (S+N)/N	Typical 6 dB ±15 kHz, 65 dB ± 50 kHz	10 Watts			Ground Unit
KING	KU192	N/A	1	See KU191	See KU191	10 Watts			See KU191
KING	KU193	N/A	4	See KU191	See KU191	10 Watts			See KU191
KING	KU194	N/A	4	See KU191	See KU191	10 Watts			See KU191
KING	KY195B	C37b C38b Class II	720	1.5 μV will provide a 6 dB min. (S+N)/N	6 dB @ ±8 kHz 70 dB @ ±25 kHz	5 Watts - 50 load	15% distort @ 80% Modulation		Panel Mounted

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
KING	KY196	C37b Class 3 C38b Class C&D	720	2 μV (hard) or less for 6 dB (S+N)/N with 1 kHz tone Modulated 30%	6 dB @ ±8 kHz Min DO-156 Class C&D 40 dB @ ±17 kHz Max 60 dB @ ±22 kHz Max	16 Watts	15% distortion @ 85% Modulation		Panel Mounted
KING	KY196E	C37b Class 3 C38b Class A&B	720	See KY196	6 dB @ ±15 kHz Min DO-156 Class A &B 60 dB @ ±43 kHz Max	16 Watts	See KY196		Panel Mounted
KING	KY197	C37b Class 4 C38b Class C&D	720	See KY196	See KY196	10 Watts	See KY196		Panel Mounted
KING	KY197E	C37b Class 4 C38b Class A&B	720	See KY196	See KY196E	10 Watts	See KY196		Panel Mounted
KING	KTR-900A	C37b C38b	360	3 μV (hard) or less for 6 dB S+N)/N with 1 kHz tone modulated 30%	36 kHz Min @ 6 dB down 65 kHz Max @ 6 dB down	20 Watts Min.			Remote Mounted

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
EDO-AIRE	RT-551 Transceiver	N/A	360	3.0 µV open circuit (1.5 µV hard) for 6 dB (S+N)/N	24.0 kHz Minimum @ 6 dB 78.0 kHz Max @ 60 dB	5 WATTS into 50 load			Panel Mounted
EDO-AIRE	RT-551A Transceiver	N/A	720	See RT-551	16.0 kHz Min @ 6 dB 44.0 kHz Max @ 60 dB	See RT-551			Panel Mounted
EDO-AIRE	RT-661 Transceiver	C37b, C38b Class II Env.Cat.	360	See RT-551	See RT-551	See RT-551			Panel Mounted
EDO-AIRE	RT-661A Transceiver	C37b, C38b Class 4 Class D Env.Cat.	720	See RT-551	See RT-551A	See RT-551			Panel Mounted
EDO-AIRE	RT-661A(A) Transceiver	See RT-661A	720	See RT-551	±8.5 kHz Min. @ 6 dB ±17.0 Max @ 40 ±25.0 Max @ 60	See RT-551			Export Version Panel Mounted

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
KING	KTR905	C37b Class I and C38b	720	See KRT-900A	20.4 Min @ 6 dB down 39.6 Max @ 60 dB down	20 Watts Min			Remote Mounted
KING	KTR905E	See KTR905	720	See KTR-900A	32.4 Min @ 6 dB down 81.6 Max @ 60 dB down	20 Watts Min.			Remote Mounted
KING	KTR9100A	See KTR905	760	6 dB (S+N)/N for 3 μV (hard) signal 30% modulated	20 kHz Min 6 dB down 34 kHz Max 60 dB down	25 Watts Min	10% Max 85% Mod	10% or less at 30% Mod	Remote Mounted
KING	KX145	N/A	720	1.5 μV (soft) for 6 dB Min (S+N)/N	6 dB @ ±14 kHz 25 dB @ ±25 kHz	2 Watts			DO-139 & DO-149 Panel Mounted Nav/Com System
KING	KX160	N/A	360	3.0 μV will provide a (S+N)/N	-6 dB @ 30 kHz -60 dB @ 85 kHz	16 Watts			Remote Mounted Nav/Com

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
KING	KX155 KX165	C37b Class 4 C38b Class C&D Class A (50 kHz sel)	720	2 μV (hard) for 6 dB (S+N)/N	6 dB±8 kHz Min 40 dB ±17 kHz Max Class C&D 60 dB @ ±22 kHz Max 50 kHz sel 6 dB @ ±15 kHz min 60 dB @ ±38 kHz Max Class A	10 Watts	Less than 85% @ 85% Mod		Panel Mounted Nav/Com
KING	KX170A		360	1.5 μV (soft) provides a 6 dB min. (S+N)/N	6 dB @ ±15 kHz 65 dB @ ±50 kHz	5 Watts			Panel Mounted Nav/Com
KING	KX175		See 170A	See 170A	See 170A	See 170A			Panel Mounted Nav/Com
KING	KX170B		720	See 170A	6 dB @ ±8 kHz 60 dB @ ±35 kHz	5 Watts			Panel Mounted Nav/Com
KING	KX175B		See 170B	See 170A	See 170B	See 170B			Panel Mounted Nav/Com

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
Collins	VHF-20A	C37b C38b Class 1	760	6 dB (S+N)/N for 3 μV signal 30 dB (S+N)/N for 100 μV signal	6 dB ±8 kHz Min for 001 Model or 6 dB ±15 KHz Min for 002 Model	20 Watts nominal 16 Watts Minimum	15% Max. @ 85% Modulation	7% Max. @ 30% Modulation	Remote Mounted
Collins	VHF-20B	C37b C38b Class 1	1440	See VHF-20A	60 dB ±17 kHz Max for 001 Model or 60 dB ±35 kHz Max for 002 Model	See VHF-20A	See VHF-20A	See VHF-20A	Export unit Remote Mounted
Collins	VHF-21	C37c C38c	Model A 720 Model B 1360	3 μV for 6 dB (S+N)/N	See VHF-20A &VHF-20B	16 Watts	Less than 15% @ 85% Modulation		Remote Mounted
Collins	VHF-22	C37c C38c	See VHF-21	See VHF-21	See VHF-20A & VHF-20B	See VHF-21	See VHF-21		Remote Mounted
Collins	VHF-250/ 250E	C37b Class II C38b	720	3 μV Mod. 30% with 1000 Hz will provide 6 dB Min(S+N)/N	6 dB @ ±10 kHz 60 dB @ ±20 kHz	10 Watts nominal 14 Watts minimum	Less than 15% @ 85% Mod		Panel Mounted

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
Collins	VHF-250S	See VHF 250/250E	360	See VHF-250/ 250E	6 dB @ $\pm$17 kHz 60 dB @ $\pm$38 kHz	See VHF-250/ 250E	See VHF-250/ 250E		Panel Mounted
Collins	VHF-251/ 251E	C37b Class II C38b	720	3 μV will provide 12 dB Min (S+N)/N	6 dB @ $\pm$10.0 kHz 60 dB @ $\pm$20 kHz	251/251S 10 Watts nominal 251E 14 Watts minimum	Less than 15% @ 85% Mod.		Panel Mounted
Collins	VHF-251S	See 251 & 251E	360	See 251/251E	6 dB @ $\pm$15 kHz 60 dB @ $\pm$38 kHz	See 251/ 251E	See 251/ 251E		Panel Mounted
WULFSBERG	WT-2000	C37b Class I & C38b	720	2.5 μV (hard) or less for 6 dB signal + noise to (S+N)/N W/1 kHz @ 30% Mod.	$\pm$8 kHz Min @ 6 dB down $\pm$15 kHz Max @ 60 dB down	20 Watts Min			Remote Mounted
WULFSBERG	WT-200	C37b Class I & C38b	720	See WT-2000	See WT-2000	See WT-2000			Remote Mounted
RADAIR	RADAIR 360		360	1.5 μV (soft) for 6 dB (S+N)/N	30 kHz @ -6 dB 80 kHz @ -60 dB	6 Watts			Panel Mounted

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
Bendix	RT-241A P/N 4102	C37b C38b Class II	360	3 µV or less for 6 dB (S+N)/N	6 dB @ 13.75 kHz Min 60 dB @ ±38 kHz Max	10 Watts			Before Mod. 2 Panel Mounted
Bendix	RT-241A P/N 4104	See 241A	360	See 241A	See P/N 4102	See 241A			Before Mod 2 Panel Mounted
Bendix	RT-241B P/N 4103	See 241A	720	See 241A	6 dB @ ±9 kHz Min 60 dB @ ±38 kHz Max	See 241A			With Mod.2 Panel Mounted
Bendix	RT241B P/N 4105	See 241A	720	See 241A	See P/N 4103	See 241A			With Mod.2 Panel Mounted
Bendix	RT241A P/N 4104	See 241A	360	See 241A	See P/N 4103	See 241A			With Mod.2 Panel Mounted
Bendix	CN-2012A	C37b Class 4 C38b Class C	720	4 µV Max for 6 dB (S+N)/N	6 dB Max.@ ±8 kHz 60 dB Min @ 25 kHz	5 Watts.	15% Max @ 350 Hz 1000 Hz 2500 Hz	25% Max @ 85% Mod 10% Max for 30% mod.	Panel Mounted Nav/Com

VHF Communication System Specifications Summary

Manufact.	Model #	TSO #	# Chan'ls	Sensitivity	Selectivity	Power Output	Distortion Transmitter	Distortion Receiver	Comments
Bendix	CN-2011A	See 2012A	720	See 2012A	See 2012A	5 Watts	See 2012A	See 2012A	Panel Mounted Nav/Com
Cessna	RT-385A	C37b Class II C38b	720	3.0 µV Max for 6 dB (S+N)/N	±8 kHz,-6 dB ±17 kHz,-40 dB ±25 kHz,-60 dB	5 Watts			Panel Mounted
Cessna	RT-485B	C37b Class II C38b	720	See 385A	See 385A	10 Watts			Panel Mounted
Cessna	RT-1038A	C37b Class II C38b	720	1.5 µV for 6 dB (S+N)/N	See 385A	16 Watts			Remote Mounted

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